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MSHGEN DOCUMENTATION (VAX-11/750 VERSION) - A MESH GENERATING PROGRAM FOR FINITE ELEMENT ANALYSIS OF TWO DIMENSIONAL STRUCTURES

N.A. Toews, Y.S. Yu and A.S. Wong
Rock Mechanics Laboratory

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N. A. Toews*,Y. S. Yu* and A. S. Wong**

ABSTRACT

MSHGEN is one of the component programs contained in the *SAP2D* system. It is a mesh generator that produces finite element output data for *MSHPLT* and *SAP2D*, and was originally developed on a CDC computer system. An extensive modification to MSHGEN, in accordance with ACSII 77 Fortran standard, was carried out in 1984 in order to make it more portable for other computer systems and to permit its use on a VAX-11/750 computer.

MSHGEN has been thoroughly tested and extensively used at the Mining Research Laboratories and has proved to be versatile and convenient to use. *MSHGEN* has been programmed to include extensive error checking and the ability to generate boundary pressures as required by finite element analysis. Another feature of *MSHGEN* is the printer-plotting of the key zone diagram for a quick visual inspection of the data.

This report documents *MSHGEN*. It introduces the necessary concept to understand *MSHGEN* and provides instructions on how to use it. In addition, a command procedure, for the VAX/VMS system, is also described.

* Research Scientists, ** Physical Scientist, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa.

DOCUMENTATION SUR LE MSHGEN (VERSION VAX-11/750) - PROGRAMME GÉNÉRATEUR DE RÉSEAUX POUR L'ANALYSE PAR ÉLÉMENTS FINIS DE BIDIMENSIONNELLES

par

N. A. Toews*, Y. S. Yu* and A. S. Wong**

RÉSUMÉ

Le *MSHGEN* est l'un des programmes faisant partie du système *SAP2D*. Mis au point sur un système informatique CDC, le *MSHGEN* est un générateur de réseaux qui produit les données pour l'analyse par éléments finis, ainsi que pour le *MSHPLT* et le *SAP2D*. Coformément à la norme Fortran ASCII 77, le *MSHGEN* a été considéraablement modifié en 1984, afin de pouvoir être utilisé sur un plus grand nombre de systèmes informatiques ainsi que sur l'ordinateur VAX-11/750.

Le *MSHGEN* a été testé dans moindres détails et utilisé couramment aux Laboratoires de recherche minière; il s'est avéré polyvalent et facile á utiliser. Le *MSHGEN* a été programmé pour pouvoir détecter constamment les erreurs et exercer des pressions sur les surfaces, ce qui est essentiel dans l'analyse par éléments finis. Le *MSHGEN* permet également d'imprimer le diagramme découpé en zones, aux fins d'une inspection visuelle rapide des données.

Le présent rapport contient des renseignements sur le *MSHGEN*, entre autres, le concept qui permet de le comprendre et des instructions concernant son utilisation. Une méthode de commande pour le systéme VAX/VMS y est également décrite.

* Chercheurs scientifiques, ** Scientifique physique, Laboratoires de recherche minière, CANMET, Énergie, Mines et Ressources Canada, Ottawa.

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1.0 INTRODUCTION

"MSHGEN" is a mesh generator that produces finite element output data for "MSHPLT" [1] * and "SAP2D" [2]. This generator was originally developed on a CDC computer system and has been used extensively at the Mining Research Laboratories (MRL) for a number of years. Recently, an extensive modification to "MSHGEN", in accordance with ASCII 77 Fortran standard, was carried out in order to make it more portable for other computer systems and to permit its use on a VAX-11/750 computer. This version of "MSHGEN" is very similar to the one described in Reference [3]. The minor differences are:

(a) A printer-plot for visual inspection always appears and the size of of the plot is always 10×10 inches.

(b) The data input are in **free format** and no printer-plot size card is required.

2.0 FUNDAMENTAL CONCEPTS AND TERMINOLOGY

This section introduces the basic concepts involved in "MSHGEN" as well as the terminology needed to understand the discussion of the program.

Consider the continuous quadratic mapping defined by

$$X = \sum_{i=1}^{8} X_i N_i(\xi,\eta), \quad Y = \sum_{i=1}^{8} Y_i N_i(\xi,\eta). \text{ Here } N_1(\xi,\eta), N_2(\xi,\eta)\ldots\ldots, N_8(\xi,\eta)$$

are eight interpolating functions. The order of the interpolating functions corresponds to the key zone numbering in Figure 1.

$$N_1 = -0.25(1-\xi)(1-\eta)(\xi+\eta+1)$$
$$N_2 = -0.25(1+\xi)(1-\eta)(-\xi+\eta+1)$$
$$N_3 = -0.25(1+\xi)(1+\eta)(-\xi-\eta+1)$$
$$N_4 = -0.25(1-\xi)(1+\eta)(\xi-\eta+1)$$
$$N_5 = 0.5(1+\xi)(1-\xi)(1-\eta)$$
$$N_6 = 0.5(1+\xi)(1+\eta)(1-\eta)$$
$$N_7 = 0.5(1+\xi)(1-\xi)(1+\eta)$$
$$N_8 = 0.5(1-\xi)(1+\eta)(1-\eta)$$

* Number(s) refers to cited references

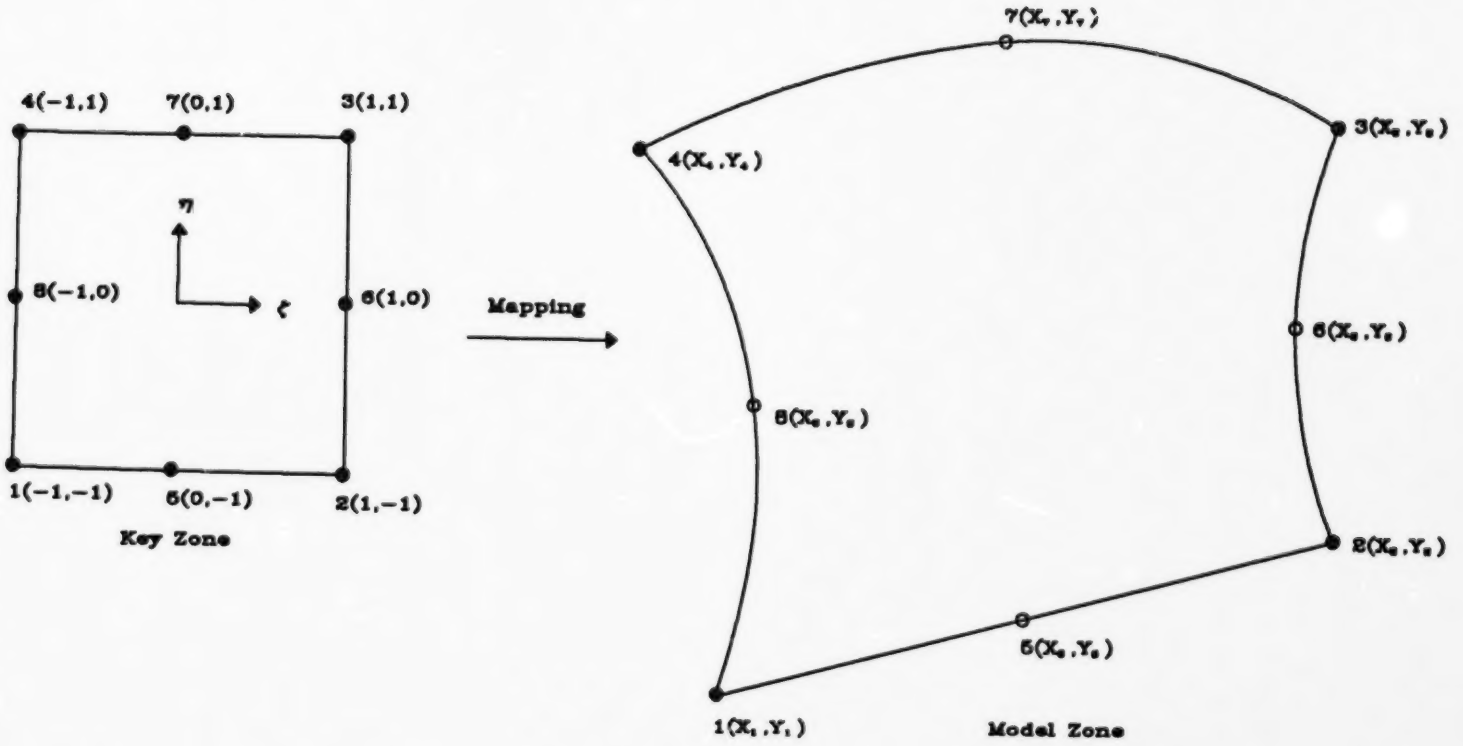


Figure 1. Fundamental Mapping Of Key Zone Onto Model Zone.

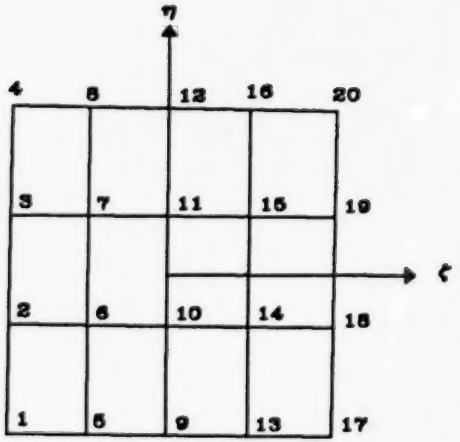


Figure 2a. Subdivision Of Key Zone.

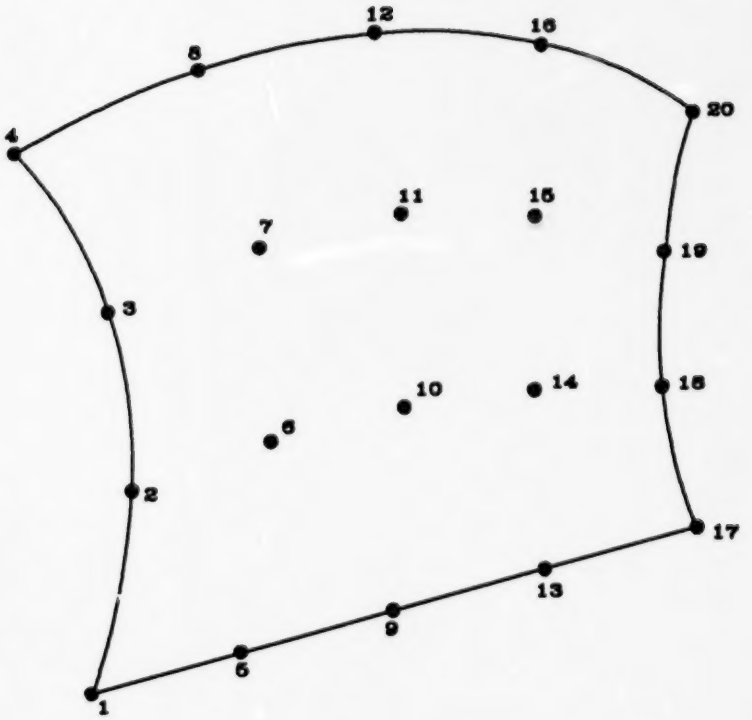


Figure 2b. Nodal Points In Model Zone.

The mapping, under certain restrictions, defines a one-to-one correspondence between points in a 2 by 2 square called a **key diagram zone** (key zone), and points in a curvilinear quadrilateral with possibly parabolic sides called a **model diagram zone** (Figure 1). The mapping is completely defined when the co-ordinates of the eight points (X_1, Y_1), (X_2, Y_2),.....(X_8, Y_8), as shown on the model zone in Figure 1, are given. These points are called the **specified points**. Points 1 to 4 are the **corner specified points** and points 5 to 8 are the **intermediate specified points**.

If the **span** of the key zone in the ξ direction is subdivided, for example into 4 subintervals and the η **span** is divided into 3 subintervals then the key diagram zone is subdivided into rectangles as shown in Figure 2a. The 20 points defined by this subdivision (Figure 2a) are mapped onto the 20 points (nodal points) on the model zone (Figure 2b). If these points are connected by straight lines (Figure 2c) then a finite element (F.E.) discretization of the model zone is produced. By increasing the number of subdivisions it is possible to approximate the parabolic sides of the model zone as closely as desired (Figure 2d).

Different **mesh grading** can be achieved by the proper choice of the intermediate specified points. Figure 3a shows the F.E. discretization of a straight sided quadrilateral when mid-point intermediate points are used. Figure 3b shows an example of the mesh grading that can be achieved with a different choice of intermediate specified points but with the same number of subdivisions.

α is defined as the fraction of the side length at which the intermediate point is selected. Thus Figure 3a has $\alpha = \frac{1}{2}$ on all 4 sides whereas Figure 3b has α's as shown. It can be shown that the following restriction, $\frac{1}{4} < \alpha < \frac{3}{4}$, must hold, if the mapping is to remain a one-to-one correspondence. Figure 4 shows for a one dimensional case, the grading that is achieved when α is varied from 0.5 to 0.25 in steps of 0.05. Note that $\alpha = 0.25$ still gives a valid discretization. For sufficiently coarse subdivisions, even larger values of α could be used. The explanation is that although the mapping may be non-unique (*i.e.*, certain points of key zone map outside the model zone), as long as none of the "nodal points" selected on the key zone belong to this non-unique area then an acceptable discretization could still result.

A further restriction of the model zone is that no interior angle of a model zone can be greater than 180°. Thus a model zone as shown in Figure 5a is illegal. Triangular zones (zones with interior angles equal to 180°) are, however, possible. Figure 5b gives an example of a F.E. discretization of such a zone.

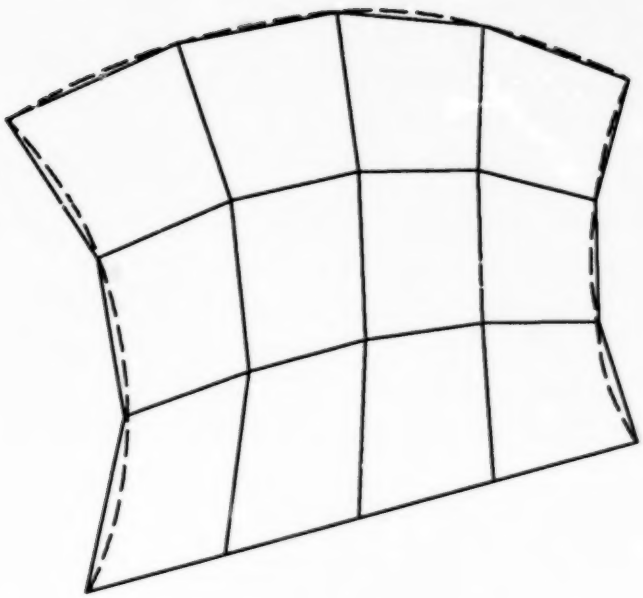


Figure 2c. Discretization of Model Zone.

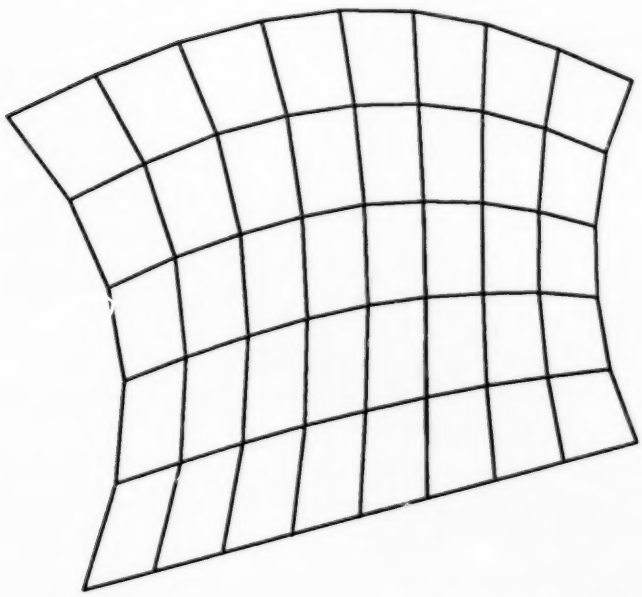


Figure 2d. Refined F.E. Discretization of Model Zone.

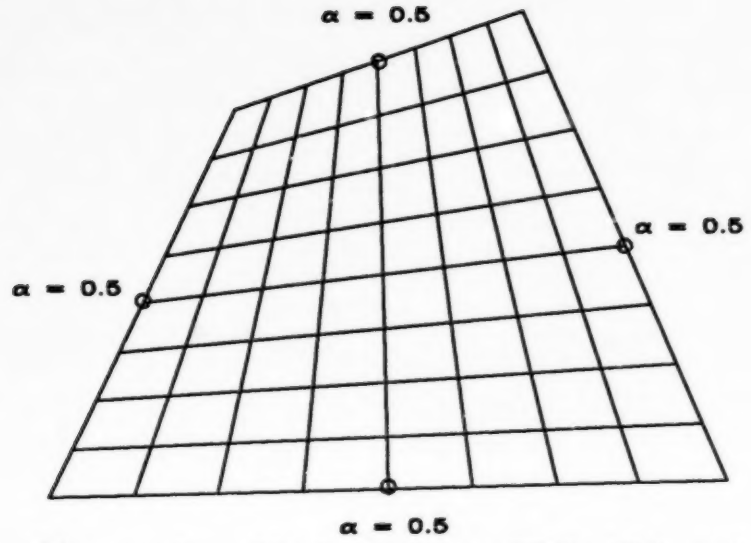


Figure 3a. Mesh Grading With Mid–point Intermediate Points.

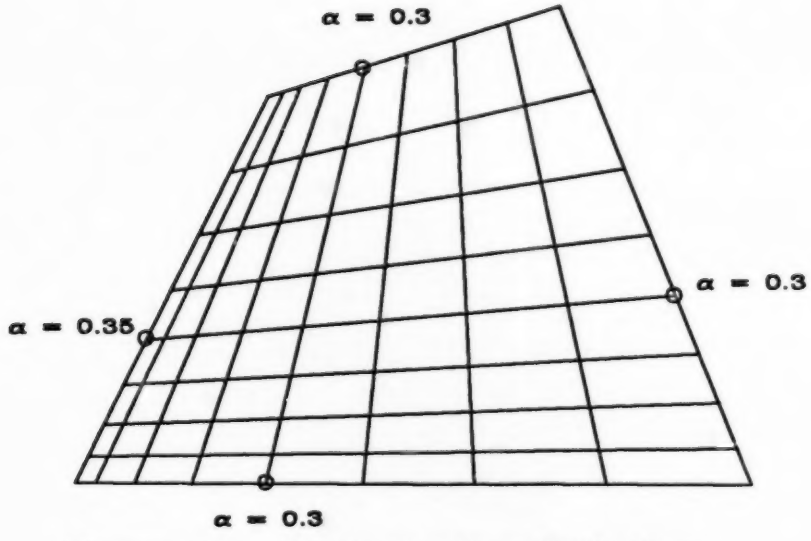


Figure 3b. Mesh Grading With Non Mid–point Intermediate Points.

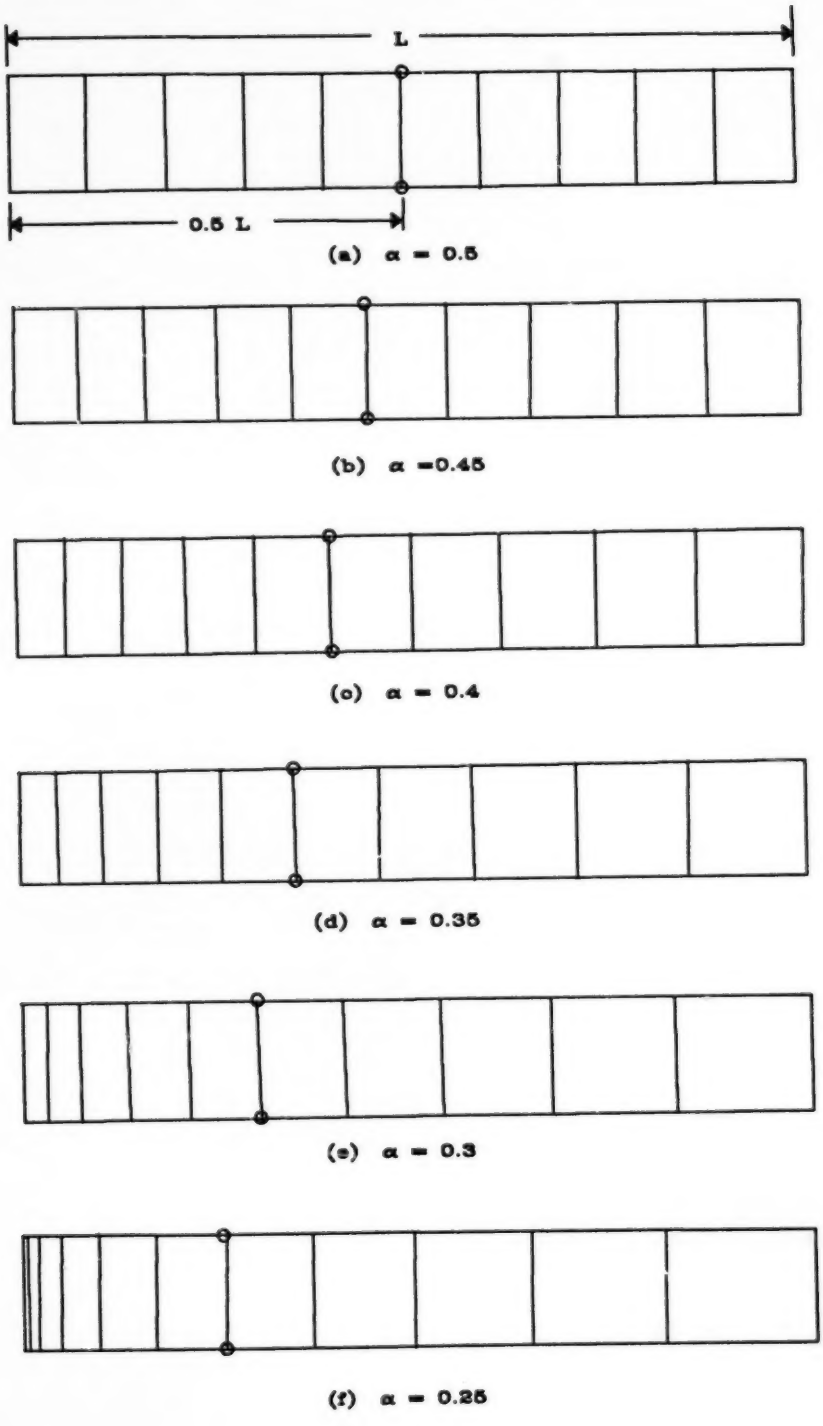


Figure 4. Grading Achieved By Different Intermediate Points.

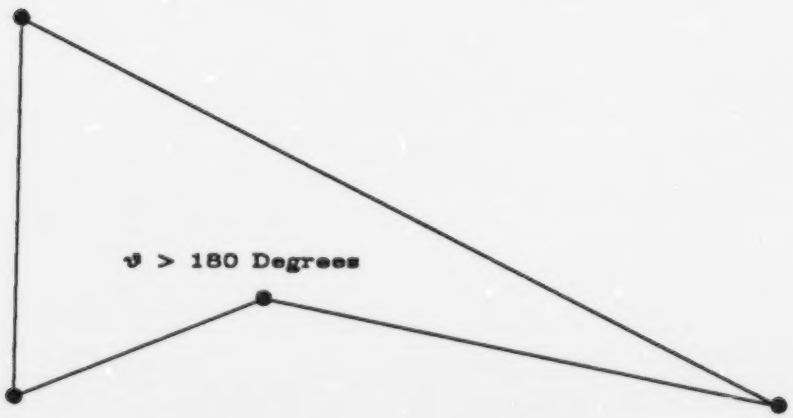


Figure 5a. Model Zone With Interior Angle Greater Than 180 Degrees Is Illegal.

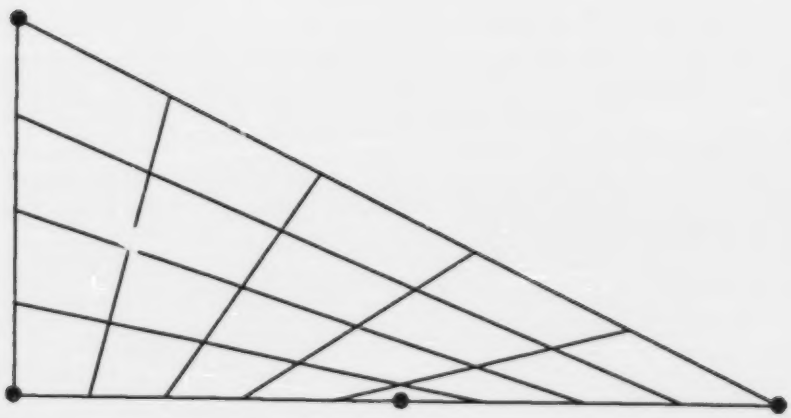


Figure 5b. Triangular Model Zone Is Legal.

Most models for which we want a F.E. discretization are considerably more complex than a curvilinear quadrilaterial. The assumption is made in "MSHGEN" that the given model can be subdivided into a number (hopefully few) of interconnected model zones and that a corresponding key diagram, made up of key zones, can be set up. The procedure for doing this is fully described in the next section.

3.0 "MSHGEN" PRELIMINARY INPUT PREPARATION

It is recommended that the following set of procedures be followed prior to preparing "MSHGEN" input data. Throughout this section it will be assumed that the no IDENTIFICATION option of "MSHGEN" (this is a feature that will be discussed later) is in effect. To illustrate the recommended procedure a simple example (Figure 6a) will be used. More realistic models, with less detail are shown in Figure 7 and 8.

Step 1 - Sketch of Structure

First **a sketch of the structure** to be analyzed should be drawn to some appropriate scale (Figure 6a).

Step 2 - Subdivision of Structure into Model Zones

This is the most critical step in the procedure if a well-graded F.E. discretization is to be achieved. Experience with the program and some ingenuity can pay large dividends here. The objective is to minimize the number of zones subject to the following constraints.

(a) Zones must be sufficiently small that an adequate representation of model curvilinear boundaries can be achieved.

(b) Zones must be selected to achieve the mesh grading appropriate for the model without generating an excessive number of nodal points and elements.

(c) A given zone must be homogeneous with respect to material properties, although distinct zones can have identical properties.

(d) If the **"cut"** option is used then a given zone must be homogeneous with respect to the **"cut number"**.

(e) Any zone corner node **interior** to the model must be the corner node of exactly 4 zones.

(f) Interior angles of zones must not be greater than 180°. However, as indicated in the last section, triangular zones are possible.

(g) To minimize the amount of hand modification to be performed later, keep in mind the procedure used by "MSHGEN" in assigning boundary condition codes to nodal points (this is discussed in Section 4.0) and select the zone subdivision accordingly.

(h) Pressures on zone sides can vary at most linearly.

Figure 6b gives a possible zone subdivision of a hypothetical slope model.

Step 3 - Assigning Specified Nodal Points

Each zone is identified and its connectivity with other zones established by specification of nodal numbers (the specified points). Numbering must be in natural integer sequence (*i.e.*, 1 to "NSPNP", where "NSPNP' is the total number of specified points). The four (4) corner nodes of the model zones must always be specified. However, when a zone side is a straight line and if no grading is required, then the intermediate point is generated by the program and need not be specified. There is no restriction on what integer (1 to "NSPNP") is associated with a given point. In specifying intermediate points for grading, remember the restrictions on α given in the last section. Mesh grading with curvilinear zones is more difficult and the restriction on the intermediate points is less clear. Highly distorted curvilinear zones sometimes give trouble when grading is attempted. In this case, it is probably better to use smaller zones. Figure 6c shows the specified points selected for the illustrative example.

Step 4 - Production of Key Diagram

As described in the previous section, with each model diagram zone we associate a key diagram zone in such a way that the assumed mapping maps the key zone to the model zone. A key diagram is made up of the associated key zones in such a way that model zone connectivity is maintained.

When this has been done, it is very important that the a key diagram have a sufficient number of zones added to it to form a complete rectangle. These key zones that are not associated with any model zone are called void zones. Completion of the key diagram to form a rectangle and the resulting regular structure makes the programming relatively straightforward. Figure 6d gives the key diagram for the example.

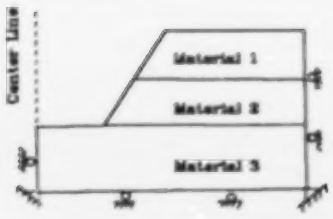


Figure 6a. Model–Hypothetical Slope With Gravity Loading.

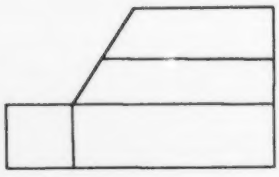


Figure 6b. Possible Zone Division Of Model.

Figure 6c. Assigning Specified Points.

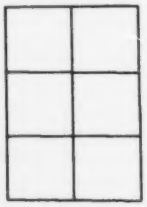


Figure 6d. Associated Key Diagram.

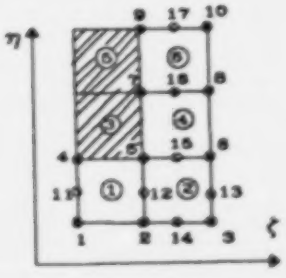


Figure 6e. One Possible Choice Of (ζ,η) With Associated Zone Numbers.

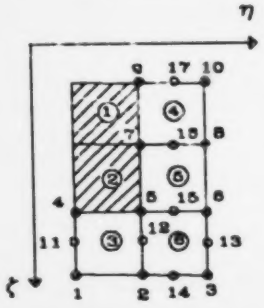


Figure 6f. Second Choice Of (ζ,η) With Associated Zone Numbers.

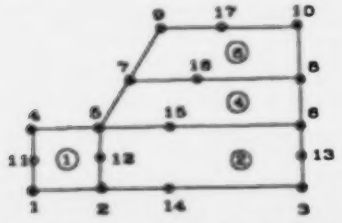


Figure 6g. Zone Numbers Transferred To Model Diagram.

- • Corner Points
- o Intermediate Points
- ② Zone Numbers
- ▨ Void Zone

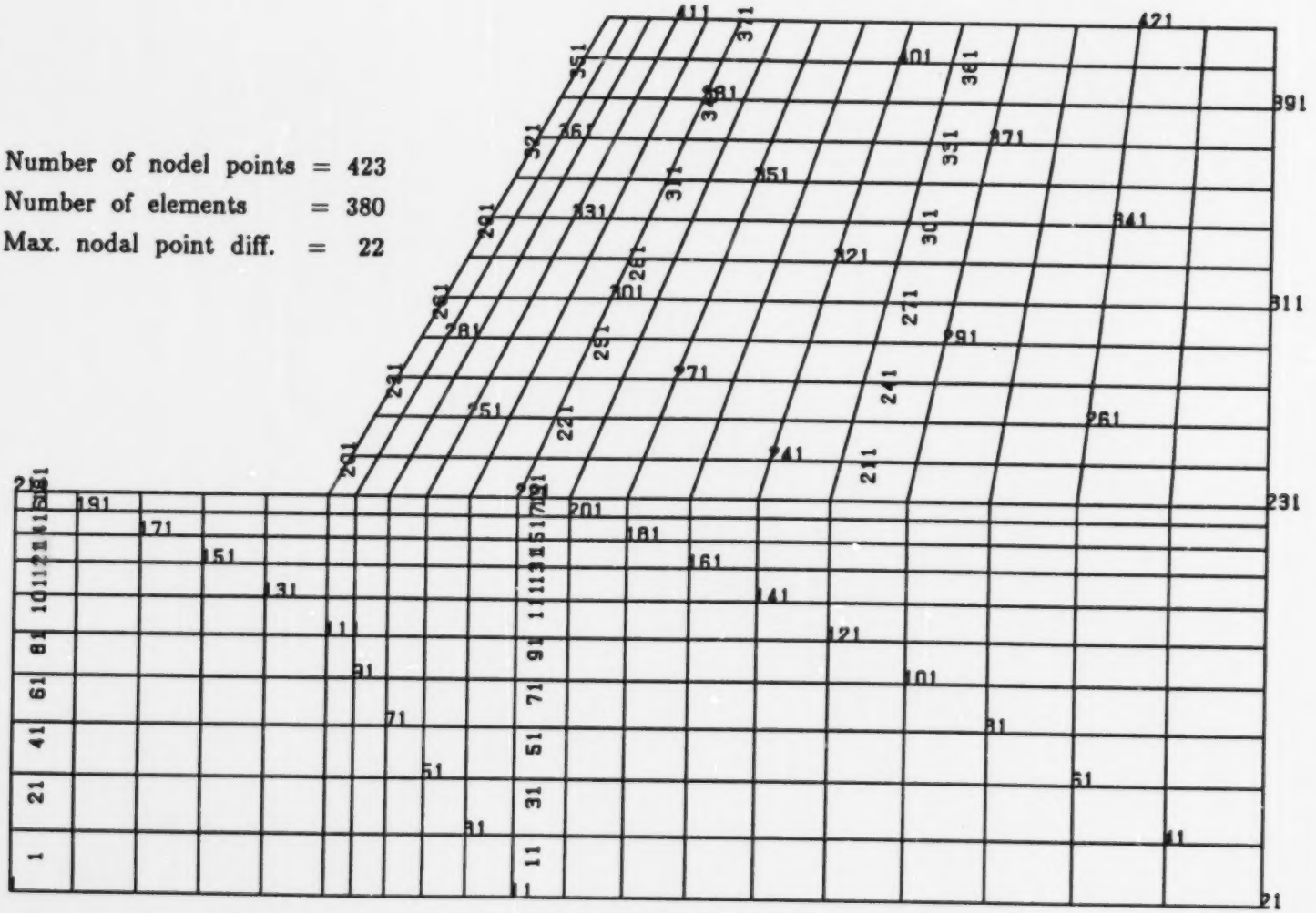


Figure 6h. F.E. Discretization Associated With Figure 6e.

Number of nodel points = 423
Number of elements = 380
Max. nodal point diff. = 24

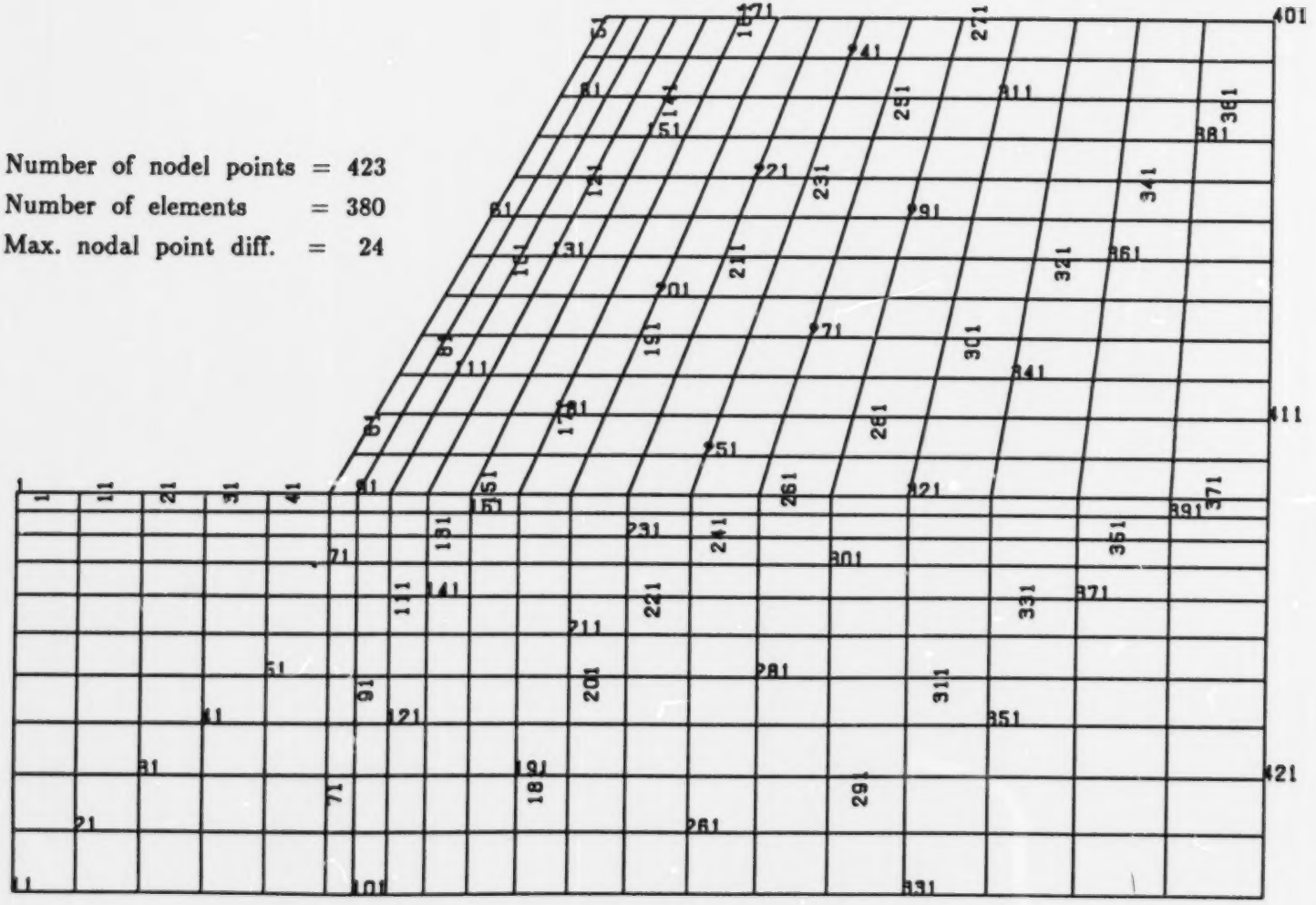
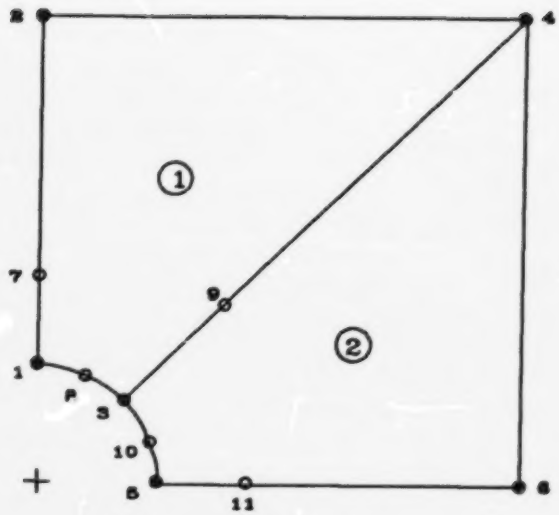
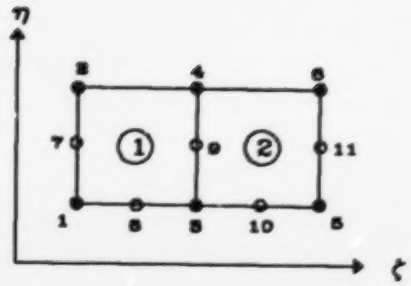


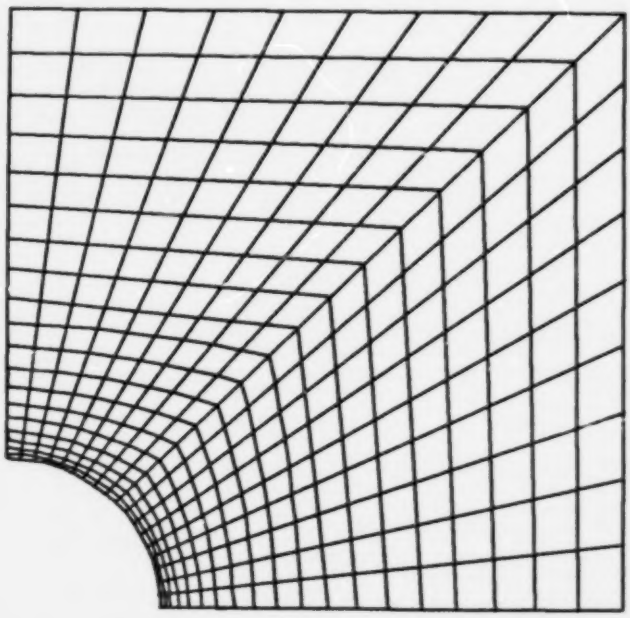
Figure 6i. F.E. Discretization Associated With Figure 6f.



(a) Model Diagram



(b) Key Diagram



● Corner Points

○ Intermediate Points

(c) F.E. Discretization

Figure 7. Plate With A Circular Opening.

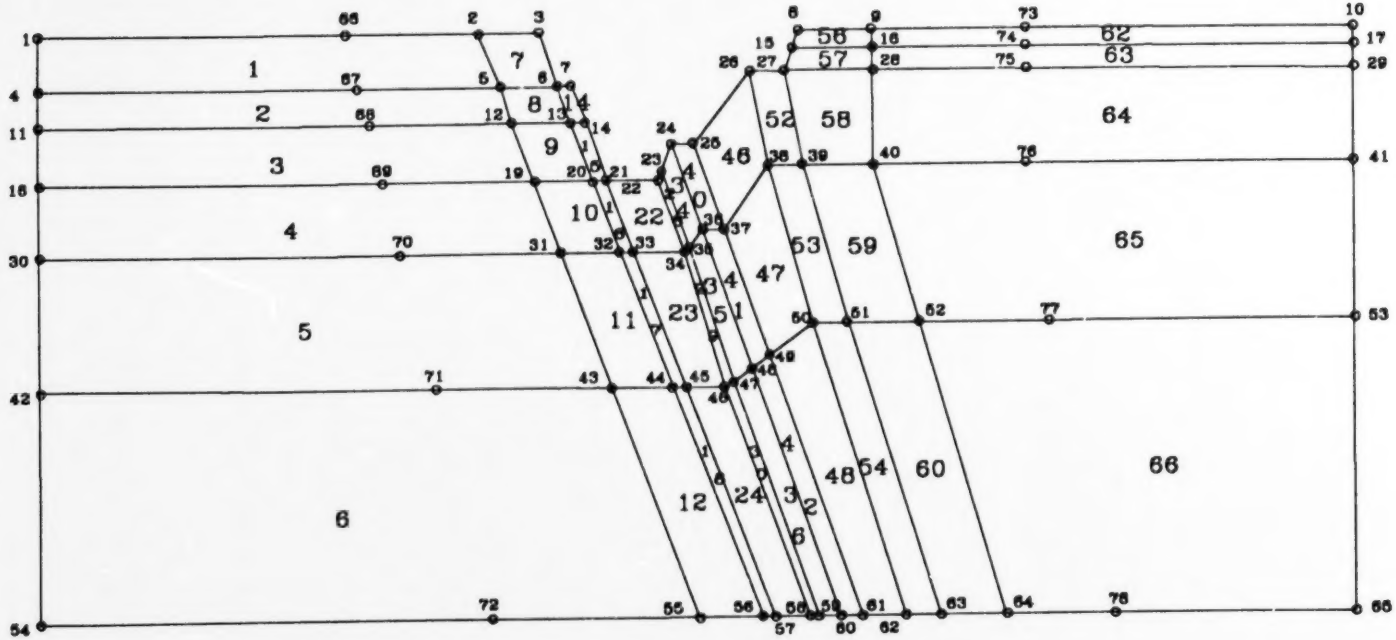


Figure 8a. Model Diagram – Simulation Of An Open Pit Mine.

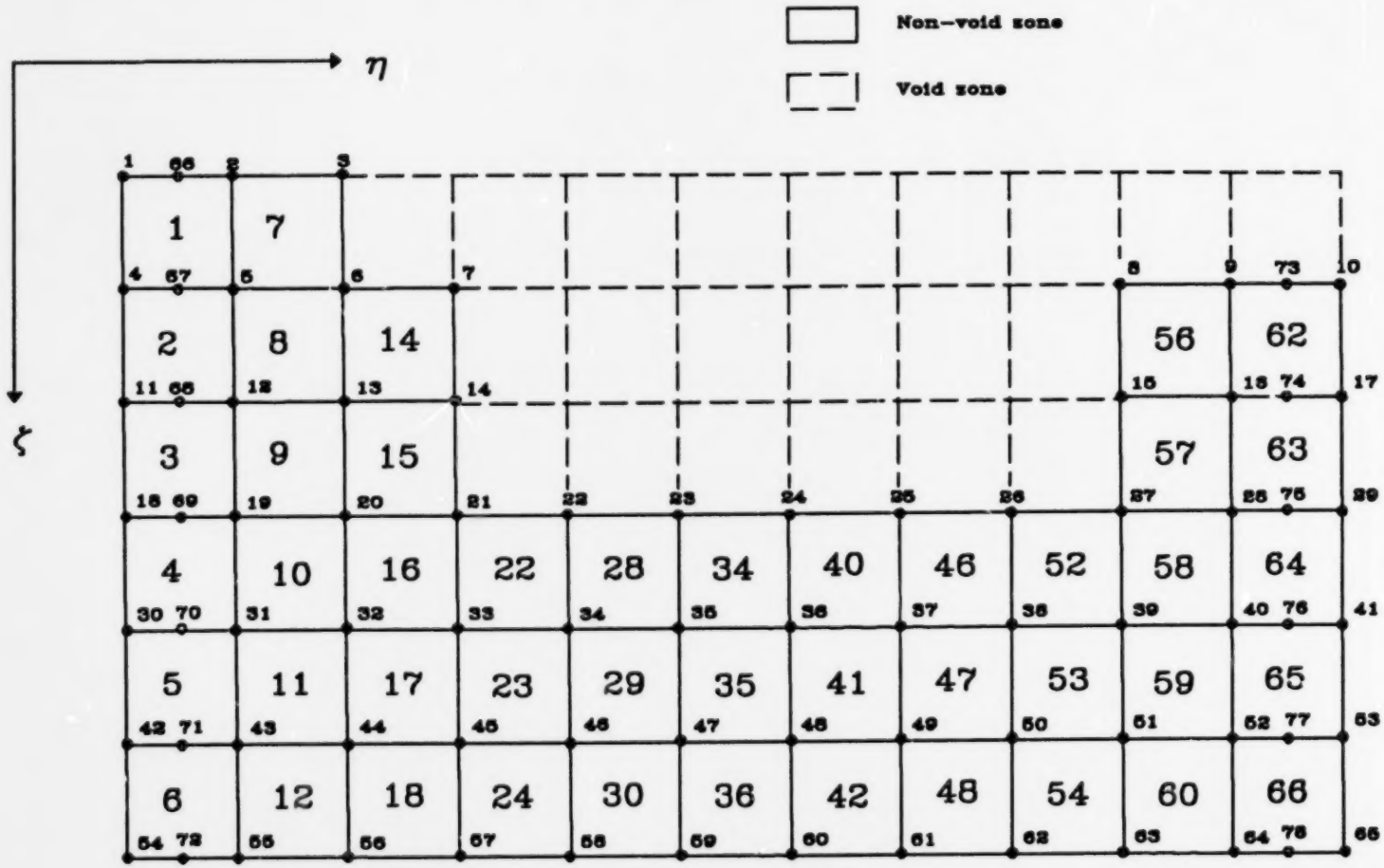


Figure 8b. Key Diagram – Simulation Of An Open Pit Mine.

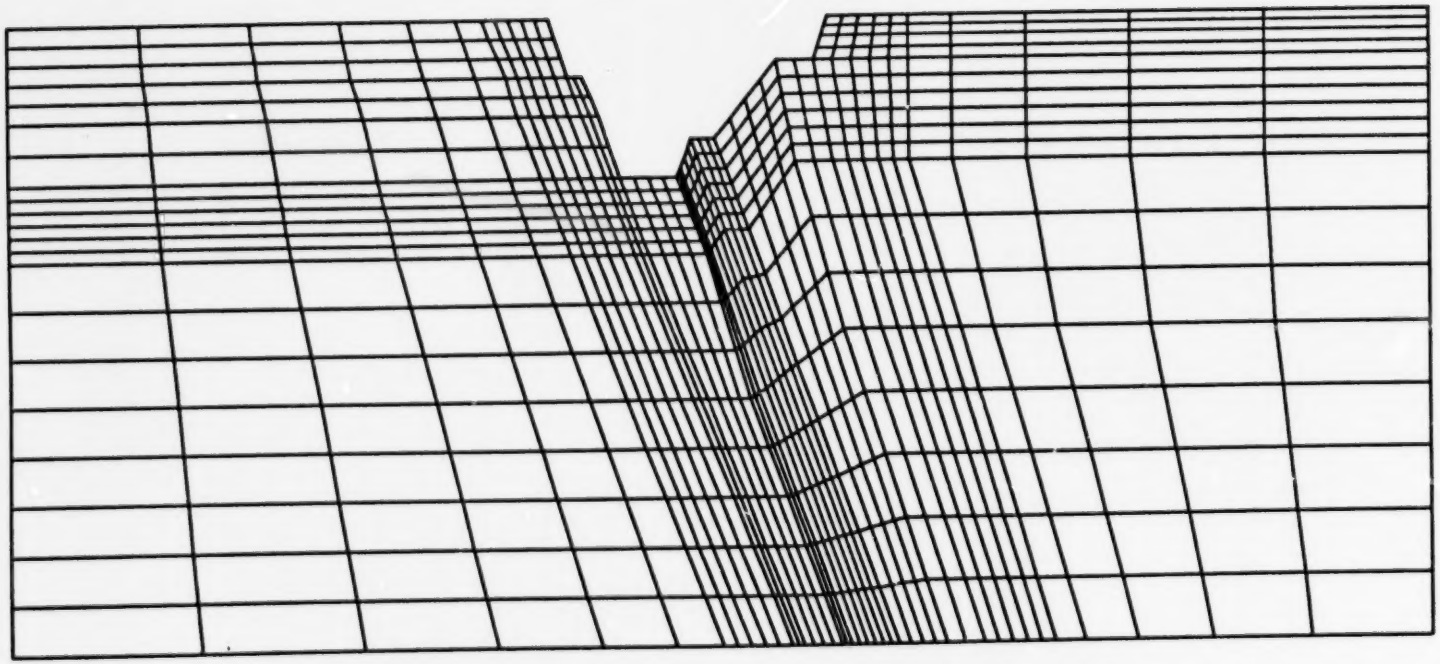


Figure 8c. F.E. Discretization - Simulation Of An Open Pit Mine.

Step 5 - Selection of Global (ξ, η) Key Diagram Reference System and Number of Zones

In general there are two possible right handed (ξ, η) co-ordinates reference systems that can be selected.

(a) Take the origin at lower left corner of key diagram rectangle. ξ is then horizontal to the right and η vertical upward (Figure 6e).

(b) Take the origin at upper left hand corner of key diagram. ξ is then vertically down and η horizontal to the right (Figure 6f).

Zones are always numbered in the manner shown in Figure 6e and 6f. Note that all zones, including void zones, are numbered. (a) or (b) of Step 5 is selected depending on which gives the smaller bandwidth ($2 \times$ node difference $+ 2$) for the resulting stiffness matrix.

"MSHGEN" always generates finite element nodal numbers in the ξ direction. Once the number of subintervals into which each span is to be subdivided is selected, the calculation of the bandwidths can proceed.

For a selected subintervals, Figures 6h and 6i show the finite element discretization, and resulting maximum bandwidth for key diagrams Figures 6e and 6f, respectively. Thus Figure 6e is the appropriate choice if bandwidth is to be minimized.

Step 6 - Transfer of Non-void Zone Numbers

Transfer the non-void key zone numbers to the associated model zones of the model diagram (Figure 6g)

This completes the preliminary data preparation phase.

4.0 "MSHGEN" BOUNDARY CONDITION CODE GENERATION

"SAP2D" [2] requires that displacement constraints be assigned to all F.E. nodal points. This is done by specifying an appropriate integer value called the **boundary condition code.**

The following describes the procedure adopted in "MSHGEN" to select values for the boundary condition codes.

In "MSHGEN", the boundary condition codes of all specified points are input and stored in an array call "NCODSP". However, only the boundary condition codes assigned to the corner specified points are used by "MSHGEN".

The procedure is as follows:

(a) Corner zone specified points become F.E. nodal points. The boundary condition codes of these points are unchanged.

(b) On the boundary of a zone, the boundary condition code of intermediate generated F.E. nodal points is taken to be the minimum of the boundary condition codes of the corner points of that zone (or those zones).

(c) All generated F.E. nodal points in the interior of a zone are given a boundary condition code of zero, *i.e.*, treated as completely unconstrained.

The above selection procedure, although somewhat arbitrary, has worked well for the type of problems encountered by the Mining Research Laboratories, CANMET, Department of Energy, Mines and Resources Canada. If the boundary condition codes are not as desired, the user can follow one of the following procedures:

(a) If there are many nodal points with incorrect boundary condition codes, it is probably best either (i) rezone the model with the "MSHGEN" boundary condition code generating procedure in mind, or (ii) modify "MSHGEN" to produce the correct F.E. code.

(b) If however, only a few points need changing (the usual case) then it is probably best to hand modify the "SAP2DC" [4] output.

5.0 PRESSURE GENERATION

Linearly varying pressure can be assigned to zone sides. These pressures are then generated for the elements produced (See Section 7.0 for details).

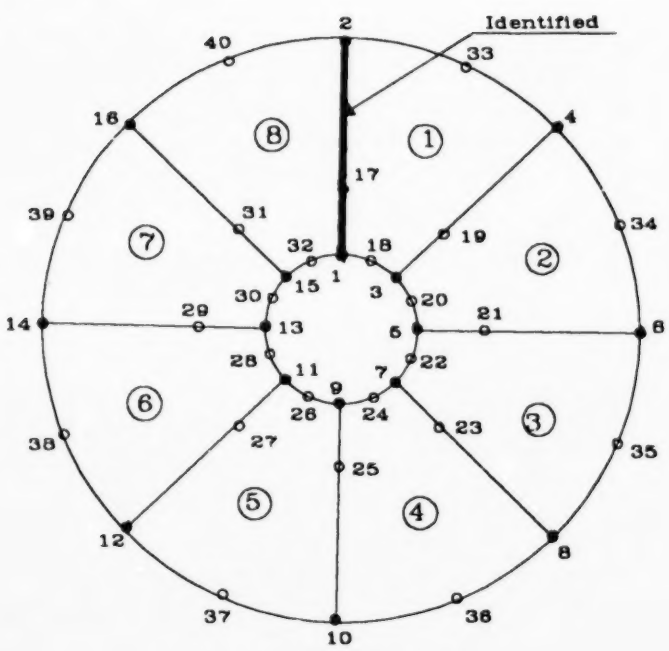
6.0 "MSHGEN" IDENTIFICATION FACILITY

Discussion of the identification facility feature of "MSHGEN" will be brief with one illustrative example. It is an infrequently used feature of "MSHGEN".

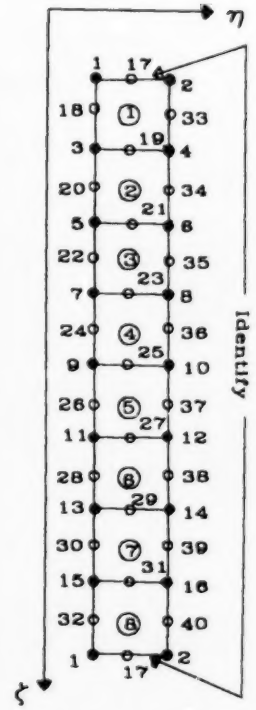
Using the procedure as introduced in Section 3.0, it would be difficult, if not impossible, to obtain a properly graded mesh for a region with multiple connectivity (say a

plate, with one or more openings). Figure 9 shows such an example. This problem can be alleviated by using the identification facility of "MSHGEN". This allows the user to draw key zones in such a way that model zone connectivity is not necessarily maintained. Thus the same specified points would occur more than one in the key diagram as shown in the example (Figure 9).

Note that the problem of minimizing bandwidth is now entirely different than for the simply connected no-identification procedure discussed previously. Thus changing the (ξ, η) global system in the example would increase the **maximum bandwidth** from 192 to 1976.



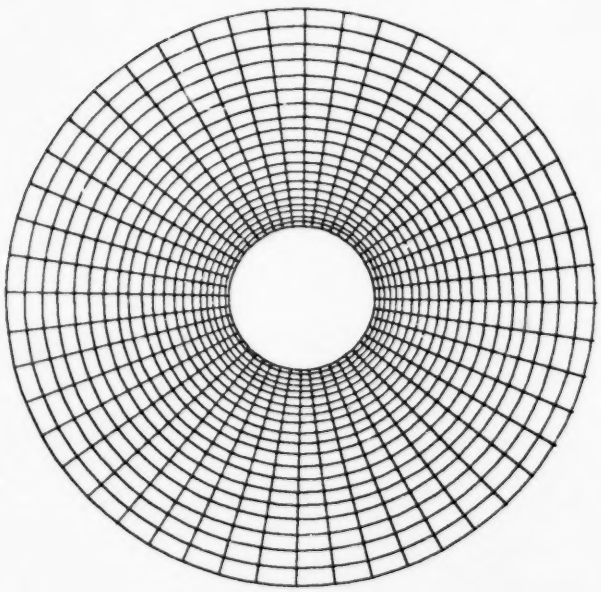
(a) Model Diagram



(b) Key Diagram

• Corner Points

° Intermediate Points



(c) F.E. Discretization

Figure 9. Use Of Identification Facility.

7.0 "MSHGEN" INPUT

A. Card #1 Title Card

READ, HDING

HDING — 80 character problem title or heading.
(This must be in quotes)

B. Card #2 Control Card

READ, NSPNP, NVZONE, NSPAN1, NSPAN2, NPROB, NSIDNT

NSPNP — Total number of specified nodal points.
NVZONE — Total number of non-void zones.
NSPAN1 — Total number of spans in the ξ direction.
NSPAN2 — Total number of spans in the η direction.
NPROB — The number of subproblems making up an excavation sequence.
NSIDNT — Identification indication, "0", no identification, "1", identification required.

C. Card #3 Card Defining Zone Subdivision On ξ Direction

READ, (NSBDV1(I), I=1,NSPAN1)

NSBDV1( ) — Array defining number of subdivisions in each zone in the ξ direction.

D. Card #4 Card Defining Zone Subdivision On η Direction

READ, (NSBDV2(I), I=1,NSPAN2)

NSBDV2( ) — Array defining number of subdivisions in each zone in the η direction.

E. Blocks of "NSPNP" Cards Defining Specified Nodal Points

READ, N, NCODSP(N), XSP(N), YSP(N)

N — Specified nodal point number.

NCODSP( ) — Boundary condition code of specified nodal point N. Table 1. defines all the possibilities.

XSP( ) — X - co-ordinate of node N.

YSP( ) — Y - co-ordinate of node N.

Note : The cards specifying the nodes must be in sequential order 1 to"NSPNP".

Code	Constraint At Node "N"
0	No constraint on displacements
1	X - displacement = 0.0
2	Y - displacement = 0.0
3	X & Y displacements = 0.0

Table 1 Boundary Condition Code

F. Block of Cards Defining the Non-void Zones

With each non-void zone there is associated 1-5 cards as follows

Card #1 Zone specification

READ, N, (IZ(J,N), J = 1,8), MATZ(N), NCUTZ(N), NUMPC

N — Non-void zone number

IZ(,N) — Nodal numbers defining the non-void zone N. This is described more completely below . (See Note 1)

MATZ(N) — The material number associated with non-void zone N. This is described more completely below. (See Note 2)

NCUTZ(N) — The cut number associated with non-void zone N. If zero, it is assigned the value "NPROB+1", *i.e.*, element in this zone will never be removed. (See Note 3)

NUMPC — The number of sides (0-4) of non-void zone N with pressure applied, *i.e.*, the number of cards defining pressure loading following this card.

If "NUMPC" is greater that zero then the above card is followed by :

"NUMPC" cards defining pressure sides on zone N.

READ, NSIDE, P1, P2

NSIDE — The side number of the zone. See Figure 10 for the numbers associated with sides.

P1 — The pressure at node 1 of zone side "NSIDE". (See Note 4).

P2 — The pressure at node 2 of zone side "NSIDE". (See Note 4).

Note 1: Zone Specification

The corner nodes must always be specified. Intermediate nodes of zero are assumed by "MSHGEN" to be midpoint nodes. Once the global (ξ, η) reference system has been selected, the order in which nodes are specified is rigid. Order of node specification is counterclockwise starting with the node at (MIN (ξ), MIN(η)).

Note 2: Material Specification

Different materials should be given numbers 1 to "NUMMAT", where "NUMMAT" is the number of different materials. The reason for this is that "MSHGEN" assumes that the maximum material number equals the number of different materials.

Note 3: Cut Number

Excavation sequences can be simulated by assigning a cut number to a zone. All elements in a zone will be eliminated when the subproblem number equals the cut number. A cut number of "1" means that elements in this zone will never be used. Elements with cut number greater than NPROB (the maximum number of subproblems) will never be deleted.

Note 4: Pressure Specification

The zone sides can be assigned linearly varying pressure by giving the pressure at the side end points. The zone sides are considered as directed lines as shown in Figure 10. The initial point is P1 and the final point P2. Only constant pressure (*i.e.*, P1=P2) can be assigned on sides which are curvilinear.

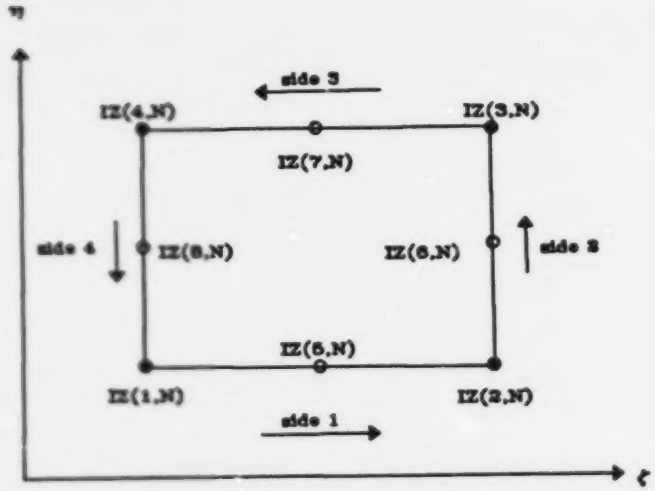


Figure 10. Specification Of Zone N.

8.0 "MSHGEN" FILE USAGE

Three files are used on "MSHGEN". These are as follows:

Logical File Name	Description
FOR005	The "MSHGEN" input data file (input);
FOR006	The "MSHGEN" print file (output);
GENOUT	The file containing the mesh data generated by "MSHGEN" (output).

9.0 "MSHGEN" COMMAND PROCEDURE

To facilitate the use of "MSHGEN", a command procedure has been written. This procedure prompts the user for the name of the input data file and also gives the user various options for the output files produced. The command procedure is listed in Appendix A. The command procedure does the following:

1) The user is prompted for the name of the input data file filename. The procedure checks that the file exists.

2) The user is prompted for the name of the file to hold the generated mesh file. The user is given the following options:

   (a) a file is produced;

   (b) no file is produced.

3) The user is prompted for the name of the file to hold "MSHGEN" print data. The user is given the following options:

   (a) a file is produced;

   (b) printer output appears on the terminal;

   (c) no print file is produced.

4) "MSHGEN" is then executed.

5) If a print file has been produced, the user is asked if it should be submitted to the system printer queue.

10.0 EXAMPLE OF "MSHGEN" INPUT

The following input data, as shown in Table 2, is used for a simulation of an open pit mine.

Table 2. Input data for a simulation of an open pit mine

```
'A Northern Ontario Mine'
78 45 6 11 3 0
3 2 2 6 3 5
6 5 2 4 2 3 3 4 2 5 5
1 1     0.0 1300.0
2 0 1000.0 1300.0
3 0 1140.0 1300.0
4 1     0.0 1180.0
5 0 1050.0 1180.0
6 0 1180.0 1180.0
7 0 1210.0 1180.0
8 0 1730.0 1300.0
9 0 1900.0 1300.0
10 1 3000.0 1300.0
11 1     0.0 1100.0
12 0 1075.0 1100.0
13 0 1210.0 1100.0
14 0 1245.0 1100.0
15 0 1717.0 1260.0
16 0 1900.0 1260.0
17 1 3000.0 1260.0
18 1     0.0  970.0
19 0 1125.0  970.0
20 0 1260.0  970.0
21 0 1290.0  970.0
22 0 1410.0  970.0
23 0 1418.0  990.0
24 0 1440.0 1050.0
25 0 1490.0 1050.0
26 0 1620.0 1210.0
27 0 1700.0 1210.0
28 0 1900.0 1210.0
29 1 3000.0 1210.0
30 1     0.0  810.0
31 0 1186.0  810.0
32 0 1320.0  810.0
33 0 1350.0  810.0
34 0 1470.0  810.0
35 0 1480.0  820.0
36 0 1510.0  860.0
37 0 1560.0  860.0
38 0 1660.0 1000.0
39 0 1740.0 1000.0
40 0 1900.0 1000.0
```

– Table 2 continued –

41	1	3000.0	1000.0
42	1	0.0	510.0
43	0	1300.0	510.0
44	0	1440.0	510.0
45	0	1470.0	510.0
46	0	1560.0	510.0
47	0	1580.0	520.0
48	0	1620.0	550.0
49	0	1660.0	580.0
50	0	1760.0	650.0
51	0	1840.0	650.0
52	0	2005.0	650.0
53	1	3000.0	650.0
54	3	0.0	0.0
55	2	1500.0	0.0
56	2	1645.0	0.0
57	2	1670.0	0.0
58	2	1750.0	0.0
59	2	1770.0	0.0
60	2	1820.0	0.0
61	2	1870.0	0.0
62	2	1970.0	0.0
63	2	2050.0	0.0
64	2	2200.0	0.0
65	3	3000.0	0.0
66	0	700.0	1300.0
67	0	725.0	1180.0
68	0	750.0	1100.0
69	0	780.0	970.0
70	0	820.0	810.0
71	0	900.0	510.0
72	0	1025.0	0.0
73	0	2250.0	1300.0
74	0	2250.0	1260.0
75	0	2250.0	1210.0
76	0	2250.0	1000.0
77	0	2300.0	650.0
78	0	2450.0	0.0

1	1	4	5	2	0	67	0	66	1	4	0
2	4	11	12	5	0	68	0	67	1	4	0
3	11	18	19	12	0	69	0	68	1	4	0
4	18	30	31	19	0	70	0	69	1	4	0
5	30	42	43	31	0	71	0	70	1	4	0
6	42	54	55	43	0	72	0	71	1	4	0
7	2	5	6	3	0	0	0	0	1	4	0
8	5	12	13	6	0	0	0	0	1	4	0
9	12	19	20	13	0	0	0	0	1	4	0
10	19	31	32	20	0	0	0	0	1	4	0
11	31	43	44	32	0	0	0	0	1	4	0
12	43	55	56	44	0	0	0	0	1	4	0
14	6	13	14	7	0	0	0	0	2	4	0
15	13	20	21	14	0	0	0	0	2	4	0

– Table 2 continued –

16	20	32	33	21	0	0	0	0	2	4	0
17	32	44	45	33	0	0	0	0	2	4	0
18	44	56	57	45	0	0	0	0	2	4	0
22	21	33	34	22	0	0	0	0	3	3	0
23	33	45	46	34	0	0	0	0	3	2	0
24	45	57	58	46	0	0	0	0	3	4	0
28	22	34	35	23	0	0	0	0	4	4	0
29	34	46	47	35	0	0	0	0	4	4	0
30	46	58	59	47	0	0	0	0	4	4	0
34	23	35	36	24	0	0	0	0	5	4	0
35	35	47	48	36	0	0	0	0	5	4	0
36	47	59	60	48	0	0	0	0	5	4	0
40	24	36	37	25	0	0	0	0	1	4	0
41	36	48	49	37	0	0	0	0	1	4	0
42	48	60	61	49	0	0	0	0	1	4	0
46	25	37	38	26	0	0	0	0	1	4	0
47	37	49	50	38	0	0	0	0	1	4	0
48	49	61	62	50	0	0	0	0	1	4	0
52	26	38	39	27	0	0	0	0	1	4	0
53	38	50	51	39	0	0	0	0	1	4	0
54	50	62	63	51	0	0	0	0	1	4	0
56	8	15	16	9	0	0	0	0	1	4	0
57	15	27	28	16	0	0	0	0	1	4	0
58	27	39	40	28	0	0	0	0	1	4	0
59	39	51	52	40	0	0	0	0	1	4	0
60	51	63	64	52	0	0	0	0	1	4	0
62	9	16	17	10	0	74	0	73	1	4	0
63	16	28	29	17	0	75	0	74	1	4	0
64	28	40	41	29	0	76	0	75	1	4	0
65	40	52	53	41	0	77	0	76	1	4	0
66	52	64	65	53	0	78	0	77	1	4	0

11.0 REFERENCES

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2. Toews, N.A., Yu, Y.S. and Wong, A.S.; "SAP2D documentation (VAX-11/750 Version) - A 2-D linear elastic finite element computer program"; Division Report MRP/MRL 85-35 (TR); Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada; Ottawa; March 1985.

3. Toews, N.A. and Yu, Y.S.; "SAP2D documentation (1975 version) 2-D linear elastic finite element computer system"; Division Report MRP/MRL 75-109 (TR); Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada; Ottawa; December 1975.

4. Yu, Y.S., Toews, N.A. and Wong A.S.; "SAP2DC documentation (VAX-11/750 Version) - An interface program for the finite element program SAP2D"; Division Report MRP/MRL 85-34 (TR);Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada; Ottawa; March 1985.

APPENDIX A

"MSHGEN" COMMAND PROCEDURE

```
$ !                MSHGEN  COMMAND PROCEDURE
$ !
$ PRINTFILE := ""
$ ON CONTROL_Y THEN GOTO ABORT
$ ON ERROR THEN GOTO ERROR
$ WRITE SYS$OUTPUT "YOU ARE RUNNING THE MSHGEN COMMAND PROCEDURE"
$ !
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT "INPUT FILE REQUIRED IS:-"
$ WRITE SYS$OUTPUT "      1) MSHGEN INPUT DATA FILE"
$ !
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT "OPTIONAL OUTPUT FILE(S) PRODUCED ARE:-"
$ WRITE SYS$OUTPUT "      1) GENERATED MESH DATA FILE"
$ WRITE SYS$OUTPUT "      2) PRINT FILE"
$ !
$AGAIN1:
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT "ENTER MSHGEN INPUT FILE NAME"
$ INQUIRE MSHIN "- "
$ MSHIN = F$PARSE(MSHIN)
$ IF MSHIN .NES. "" THEN GOTO NEXT1
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT "BAD FILE SYNTAX - PLEASE RE-ENTER"
$ GOTO AGAIN1
$NEXT1:
$ MSHIN = F$SEARCH(MSHIN)
$ IF MSHIN .NES. "" THEN GOTO AGAIN2
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT "SPECIFIED FILE DOES NOT EXIST - PLEASE RE-ENTER"
$ GOTO AGAIN1
$ !
$AGAIN2:
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT "ENTER NAME OF FILE TO HOLD GENERATED MESH DATA"
$ WRITE SYS$OUTPUT "   USER CAN ENTER:"
$ WRITE SYS$OUTPUT "      filename  - A VALID FILE NAME"
$ WRITE SYS$OUTPUT "      <CR>      - NO MESH DATA FILE PRODUCED"
$ INQUIRE GENFILE "- "
$ IF GENFILE .NES. "" THEN GOTO NEXT2
$ GENFILE := "NL:"
$ GOTO AGAIN3
$NEXT2:
$ GENFILE = F$PARSE(GENFILE)
$ IF GENFILE .NES. "" THEN GOTO AGAIN3
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT "BAD FILE SYNTAX - PLEASE RE-ENTER"
$ GOTO AGAIN2
$ !
$AGAIN3:
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT "ENTER NAME OF FILE TO RECEIVE PRINT OUTPUT"
$ WRITE SYS$OUTPUT "   USER CAN ENTER:"
$ WRITE SYS$OUTPUT "      SYS$OUTPUT - OUTPUT WILL APPEAR ON TERMINAL SCREE
$ WRITE SYS$OUTPUT "      filename   - VALID FILE NAME"
$ WRITE SYS$OUTPUT "      <CR>       - NO PRINT FILE IS PRODUCED"
$ INQUIRE PRINTFILE "- "
$ IF PRINTFILE .NES. "" THEN GOTO NEXT3
$ PRINTFILE := "NL:"
$ GOTO GENERATE
```

```
$NEXT3:
$ PRINTFILE = F$PARSE(PRINTFILE)
$ IF PRINTFILE .NES. "" THEN GOTO GENERATE
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT "BAD FILE SYNTAX - PLEASE RE-ENTER"
$ GOTO AGAIN3
$ !
$GENERATE:
$ ASSIGN 'MSHIN' FOR005
$ ASSIGN 'GENFILE' GENOUT
$ ASSIGN 'PRINTFILE' FOR006
$ IF PRINTFILE .EQS. "SYS$OUTPUT:" THEN T132
$ !
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT "THE PROGRAM MSHGEN WILL NOW BE EXECUTED"
$ RUN DISK$USER:[FE.EXECUTE]MSHGEN
$ !
$ERROR:
$ABORT:
$ IF PRINTFILE .EQS. "" .OR. -
     PRINTFILE .EQS. "NL:" .OR. -
     PRINTFILE .EQS. "SYS$OUTPUT:" THEN GOTO NEXT4
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT "DO YOU WISH TO 'PRINT/DELETE' ''PRINTFILE' FILE"
$ INQUIRE ANSWER "(Y/N)- "
$ IF ANSWER .NES. "N" THEN PRINT/DELETE 'PRINTFILE'
$NEXT4:
$ IF PRINTFILE .EQS. "SYS$OUTPUT:" THEN T80
$ EXIT
```